Experimental Investigation on Thermophysical and Stability Properties of TiO2 /Virgin Coconut Oil Nanofluids

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Science and Technology Indonesia
e-ISSN:2580-4391 p-ISSN:2580-4405
Vol. 8, No. 2, April 2023

Research Paper

Experimental Investigation on Thermophysical and Stability Properties of TiO_2/Virgin Coconut Oil Nanofluids

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Abstract
This paper shows experimental study results on the thermophysical and stability of nanofluids of Titanium oxide (TiO_2) dispersed in high-purity of Virgin Coconut Oil (VCO). Nanofluid samples that functioned as a lubricant were prepared by a two-step preparation method at different volume fractions (0.1, 0.3, and 0.5 vol.%) and different temperatures (28, 40, and 100°C). The dynamic viscosity and density were performed using Falling Ball Viscometer and Pycnometer, respectively. The sedimentation photograph method using a digital camera was applied to analyze the stability. A maximum dynamic viscosity enhancement of 62.78% was recorded for TiO_2/VCO nanofluid with 0.5% nanoparticle volume fraction and at the temperature of 100°C). Whereas, the highest density improvement was recorded for TiO_2/VCO nanofluid with 0.5% nanoparticle volume fraction. Freshly prepared nanofluids did not show any significant change in stability. However, a trivial phase separation appeared in the samples after 8 days. The results indicated that adding TiO_2 nanoparticles increased the dynamic viscosity and density. It can be concluded that the volume in fraction has the effect to enhance the thermophysical stability of TiO_2/VCO nanofluids.

Keywords
Nanofluid, Stability, Thermophysical, Titanium Oxide, Virgin Coconut Oil

Received: -, Accepted: -
https://doi.org/10.26554/sti.2023.8.2.17-24

1. INTRODUCTION

Nanofluids are part of one the most intensive research area since no optimal combination was accomplished concerning thermophysical and stability properties (Ali and Salam, 2020; Bhogare and Kothawale, 2013; Kong et al., 2017). It has been found that the thermophysical (such as viscosity and density) of nanofluid is mostly dependent on the volume fraction. The viscosity of the nanofluid is higher than the base fluid due to an increase in energy dissipation and aggregation.

Nanofluids show excellent properties, the most important issue in producing lubricant-based nanoparticles is the dispersion and stability of nanoparticles in nanofluids. It has been seen that nanofluids can be considered a potential candidate for lubricants.

A few researchers focused on the synthesis of mineral oil-based lubricants. There have been limited studies concerned with the synthesis of nanofluids-based lubricants (Azizie and Hussin, 2020; Shafi and Charoo, 2018; Kotia et al., 2018; Shahnazar et al., 2016; Zawawi et al., 2018). In preparing the nanofluid-based nano lubricant, the type, mass, and volume fraction of nanoparticles are the main challenge due to these effects on the thermophysical and stability of nano lubricant.

Stability is the main challenge of nanofluid which is crucial in its application as a lubricant. Some techniques/methods have been adopted to enhance the stability of nanofluid such as surfactant addition, pH value controlling, ultrasonic and magnetic steering, ball milling, electrostatic and electrosteric stabilization. The optimum time for sonication and stirring has not been optimized yet. Moreover, the type of nanoparticle and volume fraction on the thermophysical and stability properties are not determined yet (Harish and Rao, 2020; Huminic and Huminic, 2018; Sidik et al., 2015). Therefore, this research is aimed to investigate the thermophysical properties (dynamic viscosity and density) and stability of TiO_2/VCO nanofluids which functioned as nano lubricants.

2. EXPERIMENTAL SECTION

2.1 Materials

Metal oxide material is chosen as nanoparticles which are dispersed in the base fluid because of its chemical stability (Darminesh et al., 2017; Deepak and Ram, 2021; Salimon et al., 2010). Titanium oxide (TiO_2) nanoparticle calcined 99% extra

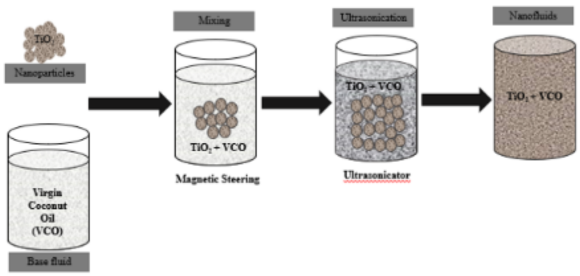

Figure 1. Schematic of The Two-Step Method in The Synthesis Process of TiO_2/VCO Nanofluids

pure supplied by Loba Chemie Pvt. Ltd, India. Commercially "BACO" Virgin Coconut Oil (VCO) produced by Kulaku Indonesia (www.kulakuindonesia.com) was used as the base fluid for lubricant.

2.2 Methods

2.2.1 Synthesis of TiO_2/VCO Nanofluids

The samples were prepared to utilize the two-step method, which is a widely used method in the preparation of nanofluids for the research (Aberoumand and Jafarimoghaddam, 2017; Ahmadi et al., 2013; Giwa et al., 2021; Katpatal et al., 2017; Su et al., 2016). Three different volume fractions i.e., 0.1, 0.3, and 0.5 vol.% were varied in this study due to the lower cost of nanoparticles. For preparing the sample, the first step involves the weighing of the TiO_2 nanoparticles with a high precision electronic balance of ±0.001 g accuracy and pouring VCO basefluid into beakers. The next step is mixing process by dispersing the nanoparticles in the base fluid by applying a magnetic stirrer for 60 min at 2500 rpm. After stirring, most of the particles remain agglomerated. To ensure that a uniform nanoparticle dispersion and enhance the stability was obtained, the nanofluid samples were sonicated with an ultrasonicator (BAKU BK-1200) at the frequency of 40 kHz for 3 hours. To investigate the effect of the volume fraction of nanoparticles, nanofluid with different volume fractions were prepared as depicted in Table 1. The sketch of the two-step method in this study is shown in Figure 1.

The volume in fractions of TiO_2/VCO nanofluids was calculated based on the mass fraction of the dispersion as:

$$\phi = \frac{m_{np}/\rho_{np}}{m_{np}/\rho_{np} + m_{bf}/\rho_{bf}} \times 100 \quad (1)$$

where m_{np}, m_{bf}, ρ_{np}, ρ_{bf} are the mass and density of nanoparticle and base fluid, respectively. While ϕ is volume concentration in fractions.

2.2.2 Characterization of TiO_2/VCO Nanofluids

The HAAKE Falling Ball Viscometer D-1080 manufactured by Thermo Fisher Scientific has been employed to measure the dynamic viscosity of the TiO_2/VCO nanofluids. This viscometer is equipped with an integrated temperature control system to control the temperature of the samples. The viscosity values of nanofluids were measured over different volume fractions (0.1, 0.3, and 0.5 vol%) at temperature ranges of 28, 40, and 100 °C.

The dynamic viscosity was calculated based on the equation:

$$\mu = K(\rho - \rho')t \quad (2)$$

where μ, t, and K are dynamic viscosity (mPa.s), time (s), and constant of falling ball (mPa.s.cm^3/g.s), while ρ and ρ' are the density of the falling ball (g/cm^3) and nanofluid (g/cm^3).

$$\rho = \frac{m}{v} \quad (3)$$

where, m and v are the mass (g) and volume (cm^3) of the pycnometer tube, while ρ is density (g/cm^3).

Nanofluid stability was investigated by using the photographic method or visual sedimentation method using a Canon digital camera of 24.4 Mega Pixel, EOS M3 Series, 5x Optical Zoom Cyber-shot. This method has been employed to observe the forming of sediment in nanofluids as the effect of volume infraction. The nanofluids were kept in a static condition and their photographs are captured one to 7 days after preparation. Based on the Stokes law, the sedimentation velocity of nanofluids is calculated as:

$$V = \frac{(2gr^2(\rho - \rho 1))}{9\mu} \quad (4)$$

where V, g, r are sedimentation velocity (m/s), gravitation constant (m/s^2), and radius of the nanoparticle. While μ, ρ, and $\rho 1$ are the viscosity of nanofluid (kg/m.s), the density of nanoparticle, and base fluid (g/cm^3).

3. RESULT AND DISCUSSION

3.1 Thermophysical Properties of TiO_2/VCO Nanofluids

Thermophysical properties of nanofluids included dynamic viscosity and density. Figures 2 and 3 showed the dynamic viscosity and density curves at different volume fractions and temperatures).

As is shown in Figure 2, the trend of viscosity for all the samples decreased with the increase in volume fraction. With increasing volume fraction of TiO_2, the viscosity found an ascending trend. When TiO_2 agglomerate and create particles, which prevent the movement of VCO on each other, hence, the viscosity will increase. From the experimental results, it was found that nanofluid shows a higher value of viscosity compared to the base fluid. The increasing viscosity is predominant at a lower temperature. The highest viscosity was observed at 28°C of temperature i.e 6.1514 to 7.4687 mPa.s. The volume fraction is the most important parameter which affects the viscosity of nanofluids. The viscosity of nanofluids effect due to

Table 1. The Prepared Sample for Experimental

Sample No.	Nanoparticle	Base Fluid	Volume in Fraction, ϕ, vol.%	Mass of TiO_2 (gr)	Volume VCO (mL)
1	TiO_2	VCO	0.1 vol.% TiO_2	1.0575	250
2	TiO_2	VCO	0.3 vol.% TiO_2	3.1715	250
3	TiO_2	VCO	0.5 vol.% TiO_2	5.2975	250

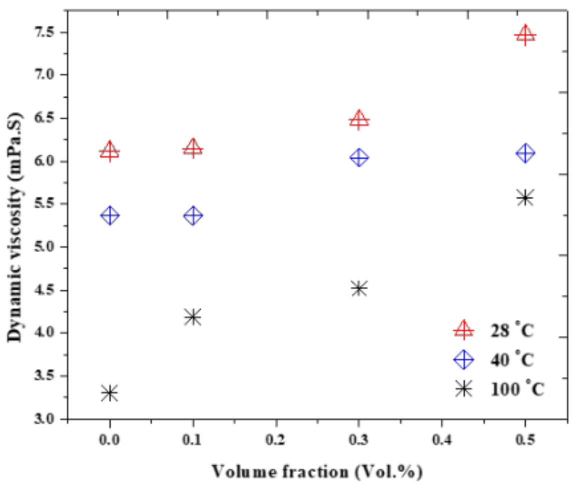

Figure 2. Viscosity of Nanofluid at A different Volume Fraction

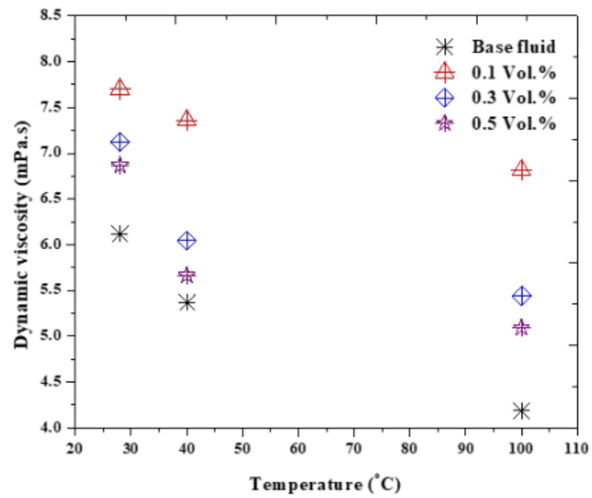

Figure 3. Viscosity of Nanofluid at Different Temperatures

the wt% of nanoparticles. It increases with the increase in particle volume fraction (Moldoveanu et al., 2018; Mukherjee et al., 2021). The more volume fraction, the more difficult to move out of the contact zone in the lubrication area. Moreover, the addition of TiO_2 nanoparticles to VCO increases the frictional shear stress between TiO_2 and VCO molecules due to which the viscosity of nanofluids increases. Therefore, the dispersion of more nanoparticles in base fluids increases the viscosity of nanofluids at the increasing volume fraction.

Figure 3 shows the effect of temperature on the viscosity of TiO_2/VCO nanofluids and their base fluid. The measurement was taken at temperatures from 28°C to 100°C and volume fractions of 0.1 vol%, 0.3 vol%, and 0.5vol.%. From the graph, it can be observed that the viscosity of the TiO_2/VCO nanofluids decreases with the temperature increment. The increased interaction between nanoparticles and base fluid molecules is due to the restriction of oil layer movement and Vanderwall's force between the molecules. The reduction of viscosity at high temperatures is due to the weakening of the intermolecular forces between TiO_2 nanoparticles and base fluid (VCO). The results showed a significant reduction in viscosity for all samples at the temperature increased from 28°C to 100°C. The viscosity of nanofluids shows an exponential decrease with temperature rise (Wanatasanappan et al., 2020). The maximum reduction of viscosity is observed for TiO_2/VCO nanofluid with a volume fraction of 0.1 vol% with a reduction of approximately 62% (7.669 to 6,8145 mPa.S). Therefore, the dispersion of more nanoparticles in base fluids decreases the viscosity of nanofluids at increasing temperatures.

In Figure 4, the density is linearly increased with the increase of volume fraction. The density value for each volume fraction is 0.943, 0.983, and 0.995 g/cm^3. The density increased by 2.3%, 6.6%, and 7.9% at 0.1, 0.3, and 0.5% of volume fraction, respectively. The density improved due to the addition of nanoparticles in pure virgin coconut oil. The higher the volume fraction, the more nanoparticles are in the pure base fluid (Kedzierski et al., 2017; Kedzierski, 2013). The more nanoparticle in VCO, the higher density of TiO_2/VCO nanofluids.

3.2 Stability of TiO_2/VCO Nanofluids

The photograph results of each sample were taken at equal intervals of time (just eight days after preparation). Sedimentation level indicates the degree of stability. It is seen from Figure 5 doesn't show the visible sedimentation of TiO_2 nanoparticles. It means that the prepared nanofluids are stable just after preparation. The stability is indicated with no sedimentation occurring. To evaluate the degree of stability, these pictures were compared after eight days.

Figures 5 and 6 describe the photographs just after prepa-

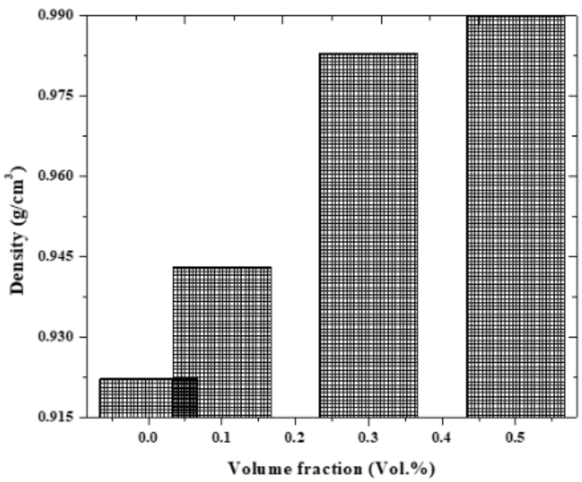

Figure 4. Density of Nanofluid at A Different Volume Fraction

Figure 5. Photographs of TiO_2/Virgin Coconut Oil Nanofluid at The Static Condition: Just After Preparation

Figure 6. Photographs of TiO_2/Virgin Coconut Oil Nanofluid at The Static Condition: Eight Days After Preparation

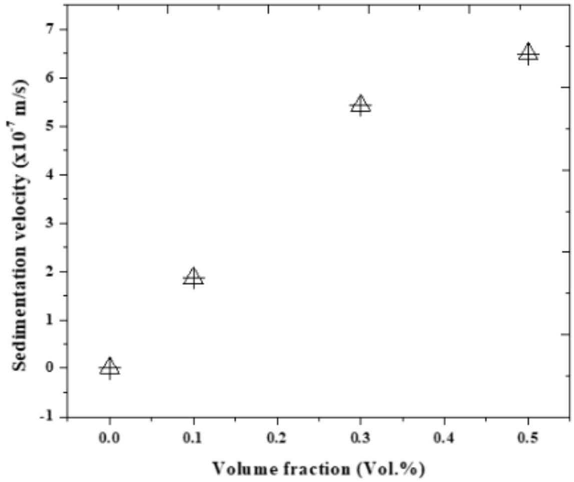

Figure 7. Sedimentation Velocity of TiO_2/Virgin Coconut Oil Nanofluids

ration and eight days after preparation of nanofluids at room temperature of 28°C. The samples were taken in the order of increasing volume fraction. The first time, freshly prepared nanofluids did not show any significant change (Figure 5). However, as shown in Figure 6, trivial phase separation appeared in the samples as the setting time increased to 8 days. It means huge aggregates/sedimentations of nanoparticles tend to settle at the bottom owing to gravity. The sedimentation level enlarged with the increase of volume fraction. It can be confirmed by the sedimentation velocity in Figure 7.

Figure 7 showed the sedimentation velocity of each sample. The range of sedimentation velocity varied from 1.8621 to $6.495x10^{-7}$ m/s. It can be seen that the velocity of sedimentation increased with the increase of volume fraction. The higher the volume fraction (0.5 wt.%), the higher the sedimentation velocity ($6.495x10^{-7}$ m/s). The highest and lowest velocity occurred in 0.5 wt.% and 0.1 wt.% of volume fraction, respectively. The increasing sedimentation velocity is caused by the highest nanoparticle in the highest volume fraction (Kumar et al., 2020; Xian et al., 2020).

4. CONCLUSION

A study has been performed on the preparation, viscosity, density, and stability of TiO_2/VCO nanofluid. Nanofluids with different volume fractions of 0.1, 0.3, and 0.5 vol.% were prepared by a two-step method. The viscosity, density, and stability measurements of the samples were executed at temperature ranges of 28, 40, and 100°C. Based on the study, the following results are obtained. The viscosity of TiO_2/VCO nanofluids increased with volume fraction and decreased with temperature rise. The density decreased concerning temperature and increased for the volume fraction. The prepared TiO_2/VCO nanofluids showed good stability for 8 days. The stability of nanofluids was hampered by the addition of nanoparticles and aging. Sedimentation degree i.e., level and velocity of TiO_2/VCO nanofluids increased with increasing volume fraction.

5. ACKNOWLEDGMENT

The publication of this paper was supported by the DIPA of Universitas Sriwijaya 2021 Public Service Agency, SP DIPA-23.17.2.677515/2021, on November 23, 2021. On April 28, 2021, the Rector's Decree 0010/ UN9/ SK. LP2M. PT/2021 was issued.

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